North Sea FLOW Measurement Workshop

Paper 9.2

Celebrating Quarter of a Century of Gas Ultrasonic Custody Transfer Metering

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1 INTRODUCTION

25 years have passed since the first production prototype ultrasonic meters for gas custody transfer were deployed. This marked the beginning of a revolution in the metering industry with a migration from conventional mechanical devices to sophisticated electronic devices and the associated diagnostics information they afforded.

The study will commence with a detailed literature review that will capture the many significant advances that have been reported by vendors and operators over the years and so provide a comprehensive ready reference for interested individuals and the industry in general.

Although the target application for the technology was transmission pipelines, benefits such as no moving parts, no protrusion into the pipeline, large rangeability, reduced footprint and diagnostic information meant that the technology was quickly applied to more arduous applications. In the early days this extension of target applications proved to be painful for both vendors and operators alike, however it was an extremely beneficial process for the industry as a whole as it rapidly accelerated product development and operational expertise. Real life examples of the many trying applications of ultrasonic meters are revisited, with dedicated commentary from operators who were directly involved in these projects. This will provide the reader with first hand, detailed insight into the operational challenges faced, the resolutions developed and lessons learned.

The paper then goes on to provide an assessment of the state of the art. Particular attention is paid to the development and content of international standards.

Finally, a discussion on the future direction of ultrasonic metering is provided

2 LITERATURE REVIEW

2.1 Gas Ultrasonic Meter Origins

We can trace the development of gas ultrasonic meters for custody transfer through early patents and publications. Early publications include Williams (1960), Birger (1961), Zalivadnyi (1963) and Brown (1965). These papers focused on the theoretical application of the acoustic technology to flow measurement and paved the way for the practical application of the technology

The first steps toward a practical development can be traced through the first gas ultrasonic patents which appeared in the mid 1970s, in particular, Parkinson et al (1973), Husse (1976) and Gassmann (1976)

These patents further developed the theory of design from an acoustic / fluid flow perspective and also discussed the electronic design requirements but did not lead directly to the production of operational meters.

A significant step toward operational meters was made by Multon et al (1980) of Ultraflux. They recognized the procedures for measuring the flow of liquids using acoustic techniques could be applied to gasses, however noted that there were two specific challenges that need to be overcome in order for a gas meter to be successfully developed.

1. The frequency of the acoustic waves is of the order one to several hundred kilo-hertz.
2. The coupling between the electrical oscillator and the transducers transmitting the ultrasonic pulses is effected by means of an impedance transformer

Multon et al (1980) presents potential solutions to these challenges in their US patent 4202210, "Ultrasonic flow meter for gases 05/13/80", and this led directly to the development of a working gas ultrasonic flowmeter for non-custody transfer applications.

The first to consider gas ultrasonic meters for custody transfer was O'Hair and Nolan (1987) of British Gas. It is interesting to look at the introduction to the BG patent as it shows that the work goes back to 1984 and that BG considers custody transfer in gas transmission pipelines.

> "*This application is a continuation of application ser. N. 801,372 (1985) which is a continuation of Sr. No. 608, 410 (1984)…. With the advent of offshore of off-shore gas supplies it is necessary to provide an extensive network of transmission pipelines in order to distribute the gas, operating at a pressure ranging from 40 to 70 bar. At present the majority of the flow metering needed to operate this system effectively is being done using orifice plate meters. However there are some serious disadvantages with these meters, including their limited flow range (about 10:1), the pressure drop they cause, the need for long straight meter runs and the substantial maintenance required*".

Whereas much of the previous work on ultrasonics had been liquid based or in the case of gas, theoretical in nature, O'Hair and Nolan (1987) actually built and tested a multipath gas meter in 1985. Included in their findings were details on the meter geometry, recommendations for meter run design, flow disturbance testing, effects of pulsations, and diagnostic methodologies. These tests basically validated the concept of using multipath ultrasonic meters for custody transfer using actual prototype meters.

The numerical calculation scheme in the BG design was based upon the well known Westinghouse model, Malone et al (1971). Westinghouse made some important contributions to liquid meters that are also valid for gas meters. Malone et al (1971) introduced the idea of multi-path meters, and subsequently proposed accurate numerical integration techniques to obtain the average pipe flow velocity from the chord velocities, Westinghouse (1976).

Zanker (2003) presented a review of the Westinghouse scheme for 2, 3, 4 & 5-path chordal meters, figure 1, where X_i represents the radial position of the i^{th} chord, V_i is the gas velocity measured by that chord and W_i is the corresponding weighting for that velocity.

	Radial Position		Centerline	Radial Position		Sum Wi
X2		0.5000		-0.5000		
W2		0.5000		0.5000		1.0000
X3		0.7071	0.0000	-0.7071		
W3		0.2500	0.5000	0.2500		1.0000
X4	0.8090	0.3090		-0.3090	-0.8090	
W4	0.1382	0.3618		0.3618	0.1382	1.0000
X5	0.8660	0.5000	0.0000	-0.5000	-0.8660	
W5	0.0833	0.2500	0.3333	0.2500	0.0833	1.0000

Figure 1. Review of Westinghouse Calculation Scheme

In the Westinghouse scheme all the paths are symmetrical about the center, and with an odd number of paths (3 & 5) one path is on the centerline. The centerline path reads about 5% higher than the average flow velocity (Zanker 2000), because the line integral is larger than the area integral. Another disadvantage with the centerline path over reading is that other paths must be closer to the pipe wall to compensate: the 3-path meter is at a radial position of 0.7071 compared to 0.500 for the 2-path, while the 5-path meter is at 0.8660 compared to 0.8090 for the 4-path.

Being close to the wall is good from a mathematical integration perspective, but not from an acoustic perspective, mainly due to shear forces and turbulence causing signal refraction and also due to signal reflection from the pipe wall. The 4-path Westinghouse meter largely avoids that issue. Another advantage of the four chord layout is that the inner chord velocity is above the average nominal velocity (1.042), while the outer chords are below the average (0.89), allowing better compensation for asymmetry. It is for this reason that British Gas selected a 4 path meter in their design, Zanker (2003).

While BG followed the Westinghouse scheme in terms of chord radial position and weighting factors, they made an important change in terms of chord layout. The Westinghouse design shows all paths in one vertical plane, however BG alternated them in two planes at right angles, with the intention of improving performance in cross flow (O'Hair and Nolan 1987); figure 2 is an extract from the original patent. It can be seen that paths 'a' and 'c' are configured in one plane and 'b' and 'd' are in a plane at right angles.

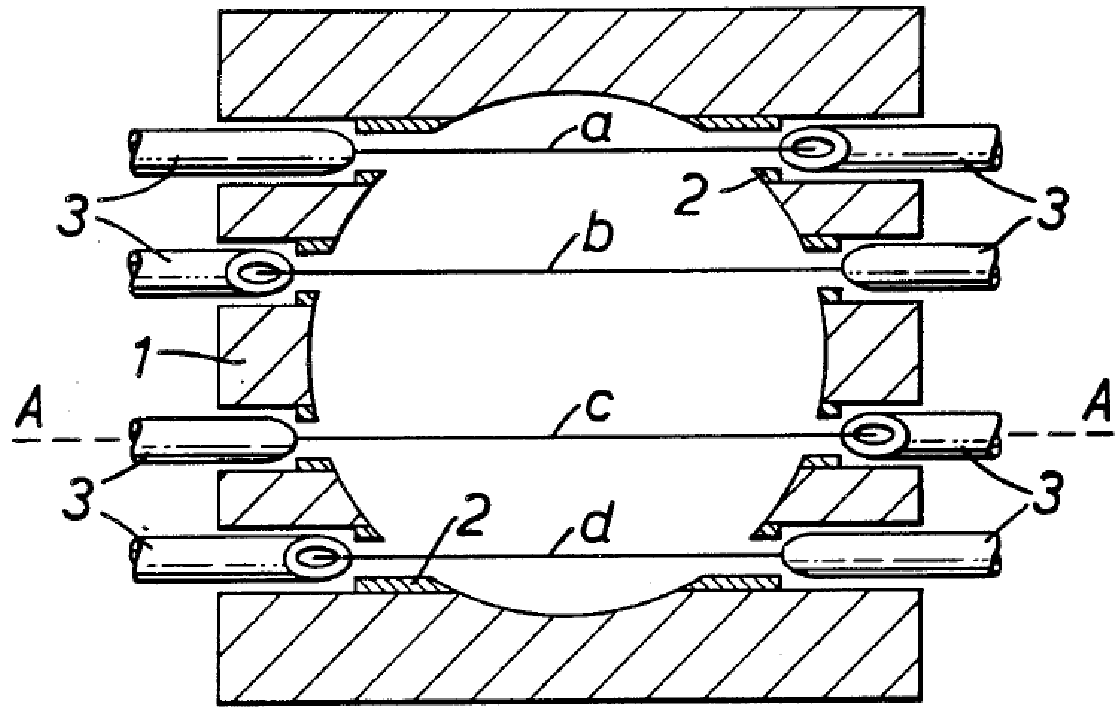

Figure 2, Original BG Path Layout for Gas Multipath Custody Transfer USM

Lunde et al (2000) present a schematic diagram of chordal meter for a single path, figure 3. Here Φ is angle of incidence of the acoustic path to the pipe axis, v is the axial velocity and v_z is the transverse velocity (cross flow).

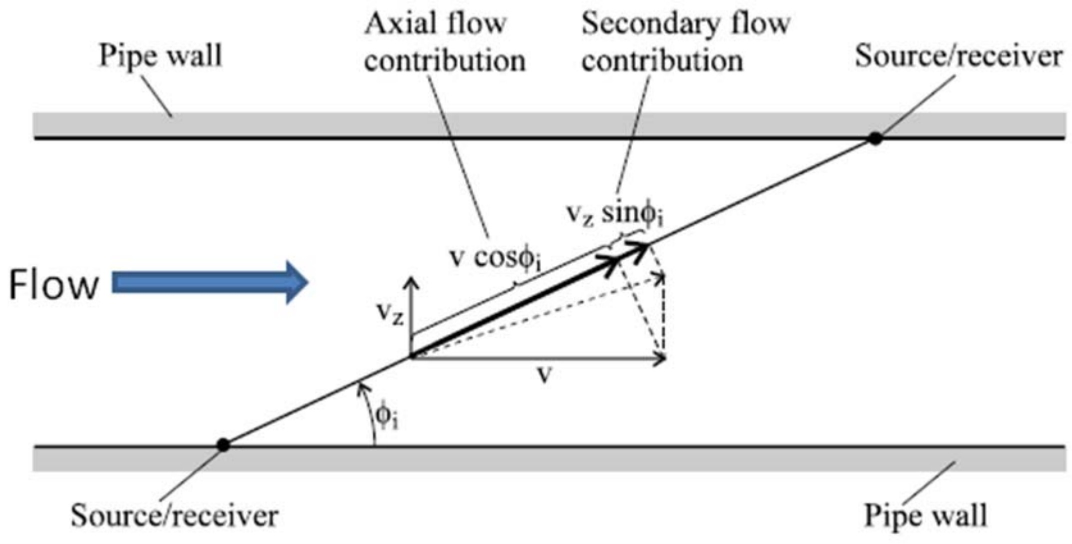

Figure 3. Schematic of a single path chordal arrangement

Both of the traditional approaches of Westinghouse and BG assume that all flow is in the axial direction, Froysa et al (2001). As such they assume that the velocity component from the flowing gas that impacts the transit times of the signals is simply v cos Φ_i. However in a real flow metering system there will be transversal flow velocity components in addition to the axial flow components, Froysa (2001), Yeh et al (2001). This transversal flow can be seen to add a new component of velocity, v_z sin Φ_i to the axial component, v cos Φ_i With all chords in one plane per the Westinghouse configuration, the transversal component impacts all chord velocity measurements in the same direction and cause a miss-measurement. However by setting the 'a' and 'd' chords in planes that are 90deg offset from each other, BG mitigated this effect since the cross flow component is additive in one case and subtractive in the other (recall the chords have the same weighting factor). Similarly this is the case for the 'b' and 'c' chords. The net effect of the cross flow component on the meter is thus negated. .

Freund et al (2004) present an interesting extension of the BG layout by defining three powerful diagnostics that can be used to identify flow disturbances using the BG design using the four chordal velocities.

- Asymmetry = (VA + VB)/(VC + VD)
- Cross flow = (VA + VC)/(VB + VD)
- Swirl = (VB+ VC)/(VA + VD).

Asymmetry compares the flow in the top half of the pipe with that in the bottom half; in good conditions it should be close to 1. Cross flow compares the chords in one plane with those in the other plane at right angles: in good conditions it should be close to 1. Swirl compares the inner chords to the outer chords and it is an indicator of swirl due to both the different radial locations and planes. In good conditions the swirl should be close to 1.042/0.89 = 1.17

Zanker (2003) points out that in general, four paths are not sufficient to resolve any arbitrary 3-dimensional flow field containing asymmetry, swirl and cross flow. However, fiscal flow measurement practice attempts to establish good flow conditions, which can certainly be verified by these ratios. Nevertheless, if the ratios differ significantly from their ideal value they can give a reasonable indication of the type of disturbance, especially if only one of the ratios has changed significantly.

Drenthen (1996) adopts an alternative approach to that described above. In his design, Drenthen (1996) utilizes a five path bounce (reflective) configuration where the signal is transmitted to the receiving transducer via a reflection from the pipe wall. The paths are arranged to measure asymmetry (single reflection centre-line paths) and swirl (double reflection outer paths), figure 4. In this arrangement acoustic waves make a total of twelve traverses of the pipe, thus providing more information on the flow than the 4 path Gaussian approach. It is argued that with this knowledge of asymmetry and swirl it is possible to make a more accurate flow measurement even in disturbed flows without any flow conditioning, Drenthen (1996).

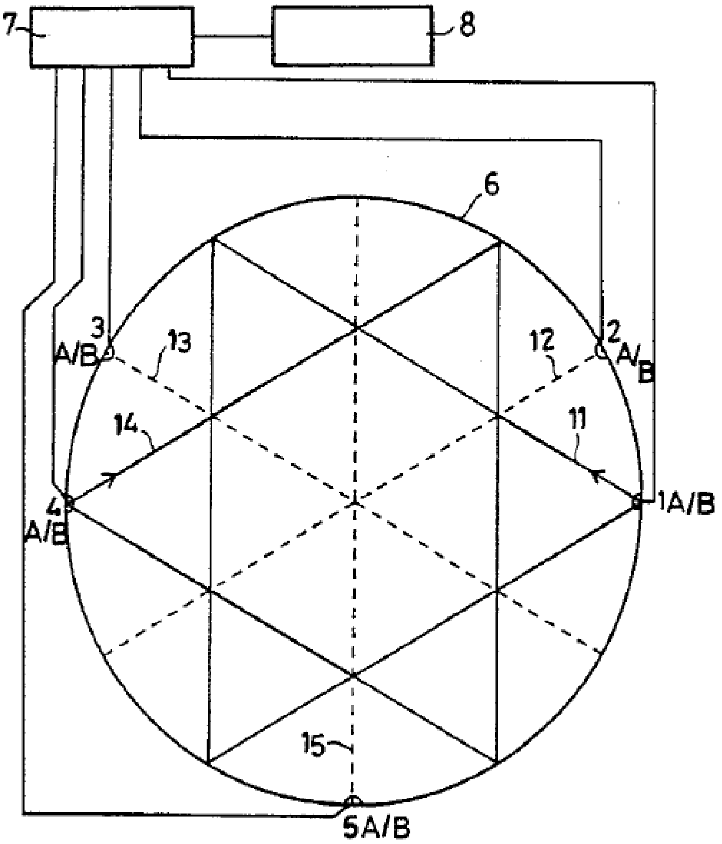

Figure 4 Alternative path arrangements for Gas Ultrasonic Meter, Drenthen (1996)

Drenthen (1996) acknowledges that with the Gaussian model “excellent results can be obtained in ideal flow conditions”, however he is concerned that it is only valid for fully axially symmetrical flow and that it does not utilize any other information relating to Reynolds number due to the fixed weighting factors. This is acknowledged by Zanker (2003) as mentioned above. Zanker (1999) describes how Reynolds number corrections are used to mitigate the circa 5% over-read associated with the centre path measurements (dotted lines 12, 13 and 15 in Figure 4) and that this correction is only valid for fully developed profiles.

Freund et al (1999) point out however that Reynolds number corrections in centre line meters are not only a function of Reynolds number but also of pipe wall roughness. The challenge here is knowledge of what the wall roughness is when the meter is installed and working. Without knowing this, the correction factor can be quite inaccurate, especially at high Reynolds numbers where the flow profile is heavily dependent on friction forces at the pipe wall, Zanker (1999).

The next significant development in gas custody transfer to take hold in the market place was the introduction of a 6 path chordal meter from FMC. This was first presented by Lygre et al (1992). The technology was developed by CMR, which was sponsored by the Norwegian Research Council, Statoil and Norsk Hydro. The result was the current 6-path design with 2 crossing paths in the two upper levels.

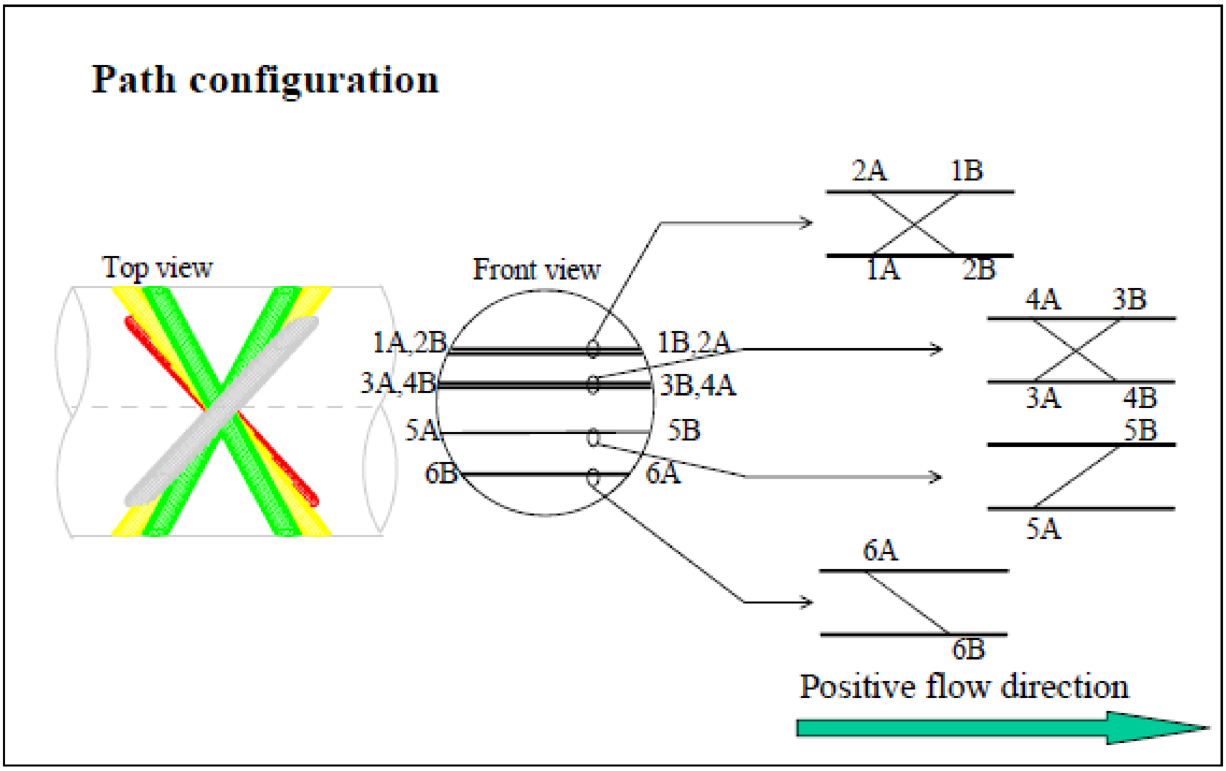

Figure 5 – FMC 6-Path Configuration

The first meters, then called FMU 700, were delivered in 1995 at the same time as the product was transferred to Fluenta, which was setup by CMR as an industrial outlet for their inventions. FMC then acquired the technology with all rights in 1996 from Fluenta.

The above review of the origins of multipath gas ultrasonic meters for custody transfer has focused primarily on patents, it is clear there was a huge amount of work done to get these early units designed and developed. The following section presents a summary of the major milestones and achievements of each on the long term manufacturers

2.2 Manufacturer Developments

2.2.1 Daniel Measurement and Control

Daniel took the BG license to manufacture the gas ultrasonic meter in 1986.
The first improvement was to introduce Automatic Gain Control (AGC) to the received signal. This ensures that the received signal amplitude is independent of the gas pressure, temperature and composition. AGC simplifies the zero crossing detection of the received signal, which is used to measure the transit time. The value of the gain established by the AGC is a measure of attenuation along the acoustic path and makes a valuable diagnostic.

The original BG analog peak detection was replaced by Digital Signal Processing (DSP). The more sophisticated DSP provides a robust reliable way of detecting a consistent zero crossing. This is an important development as it ensures confidence in the transit time measurements which determine the velocity and hence flow rate reading of the meter. The DSP also produces many useful diagnostic parameters which can be used to monitor the functionality of the meter.

The original BG USM had the acoustic path at 45^0 to the pipe axis and a maximum design velocity of 20 m/s. This was the design velocity of the complete transmission pipeline system, chosen to limit erosion and pressure loss. As industry began using ultrasonic meters more, the maximum velocity permissible in metering systems increased to as much as 30 m/s.

Daniel subsequently increased the acoustic path angle to the pipe axis to 60^0, shortening the path length and hence increasing the maximum velocity specification of the meter to >30m/s.

In 1985 the BG specification of 1% accuracy without calibration was reasonable. However with the ever increasing demand and price of gas, users are now looking for 0.1% accuracy. This has led to USM being calibrated with high pressure natural gas. The calibrations facilities are expensive but have an uncertainty of 0.2 -0.3 %, so the original uncertainty specification of 1.0% has been greatly improved upon.

A major effort by Daniel has been to improve both the internal and external diagnostics with the ultimate aim of achieving condition based maintenance and re-calibration.

As an example, the BG USM measures the path velocity (V) and the path speed of sound (c). It does not need c to determine V, however both are derived using physical dimensions of the meter and measured transit times. Since c = L/t (where L = distance between transducers and t = transit time), when L is fixed geometry then c is a direct measure of t. The 4-path USM has paths of two different lengths, so if c is the same on both path lengths, it is extra confirmation that it is correct and hence V is also correct.

Diagnostic work was extended to look at process performance also. The USM has not only the ability to measure the flow, but also the ability to diagnose the flow measurement and flow profile produced by the meter installation. The 4-path meter can give a reasonable idea of the velocity profile in terms of asymmetry, cross flow and swirl. The batch process of measuring the four individual velocities allows an estimate of turbulence, or unsteady flow, on each path, which is yet another indicator of installation conditions. So given the confidence that the USM is working correctly (measuring the transit times), it can be used to diagnose the installation. As an example, a change in turbulence can indicate that there is a blockage at the flow conditioner.

A more detailed discussion on how these diagnostics have been used to construct a Condition Based Monitoring system is described later in the paper.

2.2.2 Elster Instromet

Elster-Instromet's contribution in driving the adoption of ultrasonic flow metering internationally cannot be under-estimated. Together with Daniel, these two companies ramped the growth of the technology and positioned it as the fasted growing measurement device for custody transfer applications.

Elster first introduced coded multiple burst as a software solution for noisy applications and in-line mechanical silencers as a hardware solution. Elster showed that meters could be close coupled (flange to flange), without having any problems due to cross-talk. This allowed simpler installation of check meters and introduced redundancy. They have extended the boundaries of USM measurement to wet gas and introduce compact meter design and meter runs.

2.2.3 FMC

The FMC meter has a long pedigree: it started at Christian Michelsen Research (CMR) with fundamental research, was handed to Fluenta for commercial development and then sold to FMC.

The contribution of CMR to the whole field of ultrasonic flow measurement is much greater than the FMC meter, as seen by the many references to CMR work in this paper. CMR has made a continuous sustained effort to improve the understanding of all aspects of ultrasonic flow measurements and shared it freely with the industry. CMR has contributed to USM standardization and the continuous improvement of accuracy

2.2.4 New Entrants

As the adoption of the technology gained traction, new entrants joined the market place. An example is Sick Maihak. Sick introduced one of the first industrial Ultrasonic gas flow meter for emission monitoring in stacks in1981. For custody transfer in gas transmission Sick returned to the Westinghouse arrangement of 4 paths in the same plane. They introduced two such meters in one body on two orthogonal planes to mitigate flow profile effects and also provide complete redundancy of measurement.

Sick's main advance is in sensor technology, which permits manufacturing transducers out of titanium and uses no epoxy. These hermetically sealed sensors can be hydrostatically tested in the field without damage and permit operation with cryogenic and high temperature applications (from -160 ^{0}C to +280 ^{0}C). Sensors can operate from atmospheric pressure to 7000 psig, which allows calibration with atmospheric air.

2.3 Metering Application Development and Challenges

Reidar Sakariassen of Statoil was the first to put a gas USM onto a platform in the North Sea in 1993. He has shared some of his experience with the authors; see Sakariassen (1995 and 1997) and Frøysa et al (1996).

To convince NPD that it performed to fiscal standards Reidar designed a system with pressure (P), temperature (T), density and composition (GC) measurements. These secondary devices allowed the calculation of density and SOS, using suitable equations of state. The calculated density could be compared with the measured density and the calculated SOS could be compared with the measured SOS by the USM. The redundant measurements made it possible to determine if any measurement was in error, Letton et al (1999). This was accepted by NPD and ultimately NPD (1997) demanded that calculated SOS should be compared with the measured SOS for all USM fiscal measurements. Comparing USM SOS with calculated SOS is now an industry standard practice universally done and is also documented in AGA10 (2003)

Reidar explained that the USM was not originally planned to be used on the platform, but instead was added as an afterthought because of the lack of space available and the smaller footprint it afforded. One of meters had a pressure control valve (PCV) in close proximity. The pressure drop across the PCV created noise in the USM, which came as a surprise because the PCV had a “whisper trim”. He learnt that the whisper trim moved the noise from the audible range to the ultrasonic range to protect personnel; however the impact was that the ultrasonic noise interfered with the USM signals. The energy drop across the PCV was MegaWatts while the USM was limited to a few Watts due to its intrinsically safe design which meant signal to noise ratios were extremely small to the point where the meter struggled to function.

As a result of this experience, significant signal processing capability was developed within the meter that has hugely improved the performance in noisy environments. Moreover, a specific record and playback functionality was developed that allows post processing of signals in extreme noise environments.

Another experience was calibrating an USM at K-Lab (Norway) in the winter with the outside temperature 0^{0}C and the gas temperature at 30^{0}C. Early USMs had isolating valves on the transducer ports, to allow transducer removal. This meant that the transducer was significantly recessed from the flowing process and so there was a significant temperature gradient from the cold transducer to the warm flowing gas. This temperature gradient had a corresponding speed of sound gradient. The transmitted signal did not reach the receiver due to the corresponding refraction. A short term fix was made by insulating meters. A significant amount of research followed, Loland (1998), and longer term, the meter transducers were located at the inside diameter of the meter and an alternative mechanism for transducer removal was designed. Today all vendors have their transducers located close to the flow and most operators recommend that meters are insulated.

In the UK sector of The North Sea, Gordon Stobie of ConocoPhillips significantly extended the application of USMs. He put into practice much of the experience developed in the ULTRAFLOW (see Wilson et al) project and the associated meter prototypes were installed in the North Sea. Results were mixed for these early introductions; however valuable design lessons around piping arrangements, the use of flow conditioners, gas analysis, valve noise, uncertainty consideration and calibration / testing methodologies were learned, Stobie (1998 and 2002).

He also introduced the idea of installing USMs with very small footprints. Figure 6 shows a photograph of the allocation metering for the Jade project. This full assembly was successfully flow calibrated in order to capture the installation effects on the meter performance as a function of the meter factor, Stobie et al (2001).

Lastly, Gordon introduced the first Z-Skid, figure 7. Here two meters normally run in parallel, can be run in series by means of a cross over header and isolation valve assembly that allows them to be put in series for verification, Stobie (2002)

Figure 6. USM installed at test facility with 0D upstream straight pipes

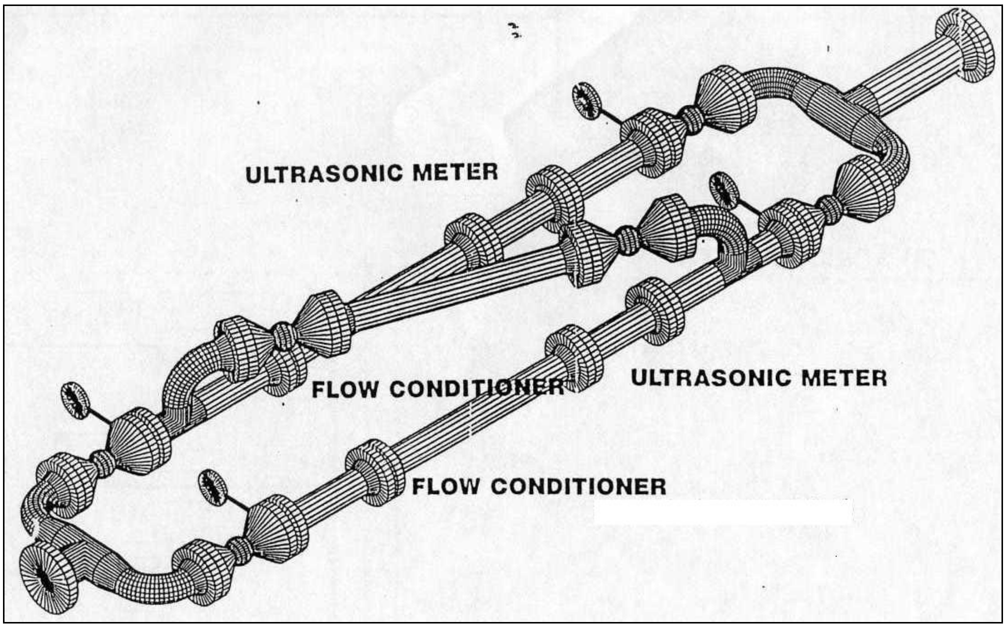

Figure 7. First instance of a z-configuration system layout for USMs

2.4 Diagnostics Development

The electronic nature of USM signal detection and timing hardware has meant that diagnostic data has been around for as long as the technology itself.
On the analogue hardware of early meters, information on the relative health of transducers was obtained using an oscilloscope to visually check the quality of the received ultrasonic pulses. Weakening transducers, cabling or circuitry could be identified, often before failure - a predictive diagnostic capability.

The advent of fully digital electronics brought about a step change in the development of USM diagnostics. Meters now use sophisticated digital signal processing (DSP) techniques, rather than simple voltage level triggers, and have fully automatic gain control (AGC), rather than manually configured, fixed, hardware derived gains.

It was now possible to store many digitized signals, and subject them to a series of tests to establish their suitability for inclusion in a flow velocity calculation. These tests could be carried out on individual signals or batches of signals; they could be statistical in nature, or concerned with voltage and signal levels, and pass / fail levels could be reported as “performance”, or “signal quality” indicators. These indicators, along with the ability to measure and report parameters like gain and signal-to-noise ratio made checking the health of the transducers and electronics far less of a burden.

The functional nature of these diagnostic parameters has been invaluable to operators looking to improve efficiency and lower cost of ownership through smarter maintenance. No unplanned shutdowns, no unnecessary interventions or routine replacements are required.

It is clear that these functional diagnostics offer a great deal in terms of maintenance advantages, but for the fiscal / custody transfer operator it was clear that other benefits could be gained.

The low uncertainty requirement of Custody Transfer requires multi-path meters to be used. The multiple flow velocity readings provided by these meters has greatly increased the information that the operator has about the flow conditions entering his meter. These velocity, or process, diagnostics, Zanker (2003) could be used to check for asymmetries in the flow, confirm and measure the presence or absence of swirl and cross flow, and detect and measure changes to the wall roughness of the upstream spool piece over time. Furthermore, the standard deviations of transit times within a measurement batch could be calculated, and any increase in this measurement of “Turbulence” was an excellent indicator of flow pulsation, or blockages in any upstream conditioner.

It became clear to the industry that these were powerful diagnostics tools. The most commonly occurring phenomena in gas pipelines, all of which were known to potentially affect metering uncertainty, could now be detected through diagnostics, rather than relying on costly and time consuming visual inspections e.g. Contamination of pipe and transducers; Liquid carry-over; Flow conditioner blockages and wall roughness changes.

The ability of the USM to measure the speed of sound of the process fluid has also had immense significance in the Custody Transfer metering world. Internationally accepted calculations, such as AGA-10, have given operators the ability to calculate speed of sound (SOS), based on gas composition, pressure and temperature. This information was already part of the measurement system calculations.

A comparison of the calculated and measured SOS is invaluable when trying to ascertain the health of the entire measurement system at start-up, and throughout its working life. Research into the uncertainties involved in the calculations, Letton et al (1999), meant that operators know what to expect from a well designed gas metering station, and for the first time, had a common variable which linked together all four pieces of instrumentation on the gas metering system.

Concerns about aspects of the metering system which normally go unverified can be tested using the SOS comparison e.g. is the sampler taking a representative gas sample? Is the pressure reduction system affecting the gas composition? These are all issues which would affect the calculation of energy, corrected and mass flows, but which can all be discounted if a low difference between measured and calculated SOS exists within the system.

Furthermore, in a typical Custody Transfer system, where the pressure and temperature transmitters, along with the gas analyzer, are routinely calibrated, they provide an independent verification of the calculated SOS, and can therefore confidently attribute any increased deviation to a change in the measured SOS – this would be indicative of a build up on the transducer faces which would influence the flow velocity calculations and the uncertainty of the USM.

In summary, we have diagnostics to tell us if the USM is failing or degrading, diagnostics to monitor for changes in the flow conditions entering the meter, and diagnostics to check overall system integrity, and check for transducer face contamination.

It was obvious that this metering technology had the potential to allow traditional calendar based maintenance and re-calibration regimes to be replaced by smarter, condition based methodologies. Nowhere in the world was this more apparent than the North Sea area where this potential was recognized in the measurement guidelines (BERR, 2003) of the UK DECC who saw it as a challenge to the industry to increase our knowledge and understanding of diagnostics to the point that the monitoring and analysis of these diagnostics could be used to confirm the ongoing stability of a meter and reduce the re-calibration burden that current legislation places on the operator.

One notable example of this is the gas metering system which was discussed in the 2008 NSFMW paper “On Line Condition Based Monitoring of Gas USM’s”. This paper detailed the technology and methodology that was implemented during an upgrade to a major gas import terminal in the Southern UK.
Prior to the upgrades the meters were removed on an annual basis for re-calibration, but had shown themselves to be exceptionally stable over the preceding years. By working with the DECC and the manufacturer, the operator was able to develop a data collection and analysis methodology which has been successfully used to defer calibrations on the meters since December 2007. It is not intended that this tool is used in place of traceable verification. This after all forms the very heart of international metrology. It does however; recognize the failings and issues with existing practices, Peterson et al (2008), and offers a practical alternative to bring about operational improvements for USM operators.

This work may also prove useful in coming years when, as is expected, the implementation of ISO-17089 becomes more common throughout other world areas. The ISO document acknowledges the power of USM diagnostics, and leaves the way clear for their use as a quality assurance tool, which can be used to extend calibrations intervals.

The latest development in diagnostics is that of actionable alerts. Here the manufacturers have responded to customer feedback that, although they appreciate the advantages of collecting diagnostics data, they need more practical information and less data. As understanding of diagnostics has increased it has become possible for manufacturers to identify common issues in gas pipelines, but, rather than generate data which has to be analysed by a metering specialist, the meter gives a simple description of the problem, along with some practical advice to the operator on what to look for. Some examples of these may be “abnormal profile”, “liquids detected in gas line”, “bore build up”, “conditioner blockage” or “SOS deviation”. This allows for meter maintenance without the necessity of having USM measurement expertise on site. If the maintenance cures the problem there is no need for a re-calibration.

It is also worth bearing in mind that the hydrocarbon industry faces a serious shortage of experienced engineers in the near future. Many operators are now looking to a “smart” or “integrated” operations philosophy where remote or un-manned locations are remotely accessed by a centralized maintenance team. The diagnostic ability of the USM, along with the remote connection ability of meters with, for example, TCP/IP Ethernet capability, greatly simplifies remote meter maintenance either by the customer, or by the manufacturer under a long term maintenance contract, further reducing operator OPEX and lowering the cost of good measurement.

One of the latest pieces of work done is by Pipeline Research Council International (PRCI). In this significant piece of work, members (end user operational companies) provided real data from field applications that was then compared with theoretical ideas. This was of significant benefit and details can be found in Floyd et al (2008)

3 STANDARDS DEVELOPMENT

It is difficult to exaggerate the importance of the role that fiscal metering operators from the North Sea area have played in the development of now globally used standards for gas ultrasonic flow measurement.

In 1998 the recommended practice report AGA-9 was released and subsequently revised in 2005. Although its committee was composed largely of members from North American gas pipeline companies, the report’s table of research literature and research activities was filled with entries from organizations from the North Sea.

Twelve years later, the industry is close to having an international standard, with ISOFDIS-17089 Measurement of fluid flow in closed conduits — Ultrasonic meters for gas — Part 1: Meters for custody transfer and allocation measurement being in the final draft stage. In the interim the widely used British Standard BS7965: Guide to the selection, installation, operation and calibration of diagonal path transit time ultrasonic flowmeters for industrial gas applications was released in 2000, then revised as recently as 2009.

Although 13 years will likely have elapsed between the release of AGA-9 and ISO-17089, the most striking feature of these documents is the amount that they have in common. This is simply a reflection of the amount of co-operation that exists between the different bodies, a reflection of the fact that safety and quality remain top priorities, and a reflection that flow fundamentals like pressure and temperature effects; wall roughness effects, protrusions and circularity etc. have not, and will not change regardless of developments in GUSM technology. Even meter uncertainty expectations have remained unchanged throughout this period.

The AGA-9 report does not classify meters, unlike the BS and ISO documents, but there is a commonality in the way they expect class 1 or “Custody Transfer” meters to perform both before and after and flow calibration, and all agree that a dynamic calibration should take place, whenever possible, to minimize uncertainty.

Unsurprisingly, the biggest evolution in the three documents is the way that they consider the diagnostic data that the meters produce, that have been discussed earlier in this paper. All three documents acknowledge the benefits of diagnostics, but it is ISO-17089 which opens up more possibilities for operators and measurement authorities. It is worthy of note that, again, the North Sea had an influential part to play. In Norway diagnostics have been used to check the health of Fiscal meters for as long as they have been in service, and the DECC opinion on USM diagnostics is very similar to the views expressed in the ISO standard.

It seems that the approach of ISO-17089, which opens the door for operators and authorities to consider and discuss the use of diagnostics to reduce re-calibration costs, is a pragmatic response to the realization that having a strict, calendar based validation methodology is proving ever more impractical and expensive, especially for the operators of larger meters in more remote areas. The industry desires the confidence all parties get from traceable metrology, but with facilities at full capacity, and an ever increasing number of meters in service around the world, it is clear that any technological advances which could improve the situation are worthy of consideration.

There has also been an evolution in the way the standards deal with installation of the meters, as the industry is acutely aware of the concerns about achieving low uncertainty performance on-site i.e. the validity of transferring laboratory derived correction factors to a customer site. It is of course possible to use flow velocity diagnostics to confirm the presence of a fully developed symmetrical flow profile, but start-up day is not the time to check for good installation!
It was therefore imperative that the standards address the issue, and it is interesting to compare the approaches.

With more of the commonality mentioned before, the earlier two documents have put the onus on the manufacturer to either:

1. Recommend at least one installation, with and without a flow conditioner, which will not create an additional error of more than +/- 0.3%, and which is supported by test data

Or

2. Specify the maximum allowable flow disturbances what will avoid creating the same additional error.

And while the original revisions of both documents also gave information of default installations, only the AGA-9 retains a default installation instruction.
Most manufacturers chose to recommend several installation options, usually backed up by independent test data, and were happy with the AGA-9 default installation recommendations

ISO-17089 has chosen a more involved " type testing" approach, where the manufacturer should provide a set of minimum upstream length requirements (Lmin) which specifies the installation requirements for the meter when installed downstream of a set of commonly encountered pipe configurations – one bend , two bends, reducer, expander etc. , and like the AGA and BS documents, the tests should be done with and without a flow conditioner, with the same limit of +/- 0.3% additional uncertainty being chosen as an acceptable deviation.

Notably, all three documents give warning to operators about the complexity of flow and installation:

"Asymmetric velocity profiles can persist for 50 pipe diameters or more downstream from the point of initiation. Swirling velocity profiles can persist for 200 pipe diameters or more. "

So there can be no doubt that operators are aware of potential pitfalls.

The fact that the standards have progressed and developed is beyond doubt, but has the development in standards improved the situation for the operators and designers of GUSM metering stations? It appears so.

For years the AGA-9 report has been a perfectly satisfactory de facto standard for the industry around the world. It's prescriptive and practical approach to selection, installation, operation and maintenance has served operators very well since its release.

Likewise, the British Standard has also been widely used outside the UK and North Sea area, and again many operators have found it invaluable. It still contains useful information on topics such as the benefits of thermal insulation, which does not appear in the ISO or AGA offerings.

If widely adopted, then the ISO-17089 looks set to further improve the work of the operator and designer. It keeps and confirms the established flow wisdom from its predecessors, but has the chronological luxury of being able to include new research and findings. It was certainly more manufacturer-centric than, say AGA-9, but in fairness the standard does not go lightly on the manufacturers, requiring them to carry out testing, and provide assurances that all are designed to make construction and operation easier. It leaves the door open for advancement in the use of diagnostics – recognising the difficulties faced by the industry, and, like the standards that have gone before, provides excellent references and appendices to improve understanding and promote development.

Here, perhaps, is a very strong case for the further integration of standards and reports, in an attempt to produce one globally accepted standard, with the obvious benefits it brings to both manufacturers producing for a global market, and also for operators as we see more and more projects transcend continents.

4 FUTURE DIRECTION

25 years have passed since the first gas ultrasonic flowmeters were used for custody transfer. In that time, a huge amount of theoretical, product development, practical application and standards development work has been done. As a result ultrasonic meters have become the technology of choice in the arena of gas custody transfer.

A major area of focus will be diagnostic utility. Currently, diagnostics serve three purposes. Firstly they monitor the meter's health and warn if there is a pending problem, e.g. transducer failure. Secondly they monitor the gas process and alert to any upsets there, e.g. pipeline contamination, blockages or liquids in the gas stream. Thirdly, diagnostics can alarm an operator if metering uncertainties are no longer being met, e.g. out of specification AGA10 comparison, as reported by Peterson et al (2008). In the future, meters will continue to offer these diagnostics, however in addition the technology will tend toward the ultimate position of being able to report a continuous and traceable, live uncertainty budget associated with its flow reading.

Moreover, meters will become self tuning. Today if a USM is confronted with a field issue, e.g. control valve noise; it is very unusual for that problem to be irresolvable. By having an engineer view the site data and diagnostics, a firmware fix can be applied to the meter. The knowledge required to arrive at that fix will be codified and implemented in the meter. As the device senses an issue it will implement a fix and so becomes auto-tuning.

Meters are predominately used in dry natural gas applications today. Future applications will build on our current wet gas knowledge, and meters will tend toward true bi-phase metering at custody transfer levels of uncertainty for both the gas and liquid components of the flow.

As the unit cost of USMs continues to fall with increased volumes being sold, the industrial bandwidth of the technology as it relates to custody transfer accuracy levels will increase. There will be a broader adoption of the technology within industrial gas applications.

Lastly there will be a commonality in methodologies and standards used in the global application of ultrasonic meters

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